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13. ABSTRACT (Maximum 200 words)

Engelhorn has conducted experimental work to determine nucleate pool boiling heat transfer coefficients for a variety of refrigerants at wide pressure and heat flux range. In this work we have compared the experimental data of Engelhorn for refrigerants R-11, R-12, R-13, R-13B1, and R-22 with those calculated from the following correlation:

$$h = \frac{2}{\sqrt{\pi}} \sqrt{k_l c_l \rho_l} \sqrt{f} + \frac{1}{6} \rho_v \lambda f D_b \frac{1}{\Delta T_w}$$

The correlation is based on two factors which are responsible for the removal of heat from a heat transfer surface in boiling. The first factor represents heat removal by transient heat conduction and the second factor represents latent heat transport removal. The data were compared for pressures ranging from 0.019 bar to 1.51 bar and the heat flux ranging from 100 W/m^2 to 102,000 W/m^2. The calculations revealed that experimental and predicted heat transfer coefficients compared very well.

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Enclosure 1

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EVALUATION OF POOL BOILING HEAT TRANSFER COEFFICIENTS FOR THE DATA OF ENGELHORN

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INTRODUCTION

Nucleate pool boiling is a very important heat transfer process in refrigeration and cryogenic industry. Due to such industrial needs many investigators have conducted experimental studies to collect the data for nucleate pool boiling. Engelhorn undertook a comprehensive experimental investigation to collect the nucleate pool boiling data for many refrigerants. He conducted such experiments for a wide range of heat flux and pressure. We have earlier developed a correlation for nucleate pool boiling heat transfer at atmospheric and subatmospheric pressures for pure liquids. This correlation was based on the underlying mechanism of boiling heat transfer. Proper consideration was given to the various heat transport factors responsible for removing the heat from the heat transfer surface in a boiling heat transfer process. The purpose of this study is to predict the heat transfer coefficients for the data of Engelhorn using the correlation we developed.

RANGE OF EXPERIMENTAL PARAMETERS FOR THE DATA OF ENGELHORN

TABLE-1

REFRIGERANTS	HEAT FLUX, W/m^2	PRESSURE, Bar
R-11	1,000 to 83,000	0.019 to 0.991
R-12	100 to 102,000	0.25 to 1.80
R-13	200 to 84,000	2.80 to 10.55
R-13B1	200 to 96,000	0.39 to 2.15
R-22	200 to 99,000	0.78 to 5.60

NOTE We calculated heat transfer coefficients mostly at subatmospheric and atmospheric pressures

ANALYTICAL CORRELATION:

A critical literature analysis suggests that there are two main factors which contribute the removal of heat from the heat transfer surface.

The first factor suggested by Mikic and Rohsenow [1] postulates that the main mechanism of heat transfer in nucleate boiling is transient heat conduction to, and subsequent replacement of, superheated layer around boiling sites.

The second factor comes during the growth of vapor bubbles and their subsequent departure. Rallis & Jawurek [2] and Paul & Abdel-Khalik [3] have suggested that the latent heat transport plays a considerable role for the removal of heat from the heat transfer surface.

Taking these two factors into consideration, Blöchl [4] developed a correlation of the following form. We modified this correlation by developing expressions for bubble emmission frequency. For bubble departure diameter, Laplace equation was used.

$$(h)_{pred} = \frac{2}{\sqrt{\pi}} \sqrt{k_l \; c_l \; \rho_l} \; \sqrt{f} + \frac{1}{6} \rho_v \lambda f D_b \frac{1}{\Delta T_w}$$

$$(h)pred = \frac{2}{\sqrt{\pi}} \sqrt{kl \;\; cl \;\; \rho l} \;\; \sqrt{f}$$

$$+ \; \frac{1}{6} \, \rho v \, \lambda \, f \, Db \, \frac{1}{\Delta Tw}$$

The first factor represents the part of the heat removed due to conduction heat transfer from the surface to the adjacent liquid layer. When the sufficient degree of superheat is reached the bubbles start nucleating on the surface. It is believed that a larger portion of heat is removed because of this conduction process in the vicinity of the wall.

The removal of heat by this conduction process can be taken into account by the product of thermal accommodation factor (given by the product of thermal conductivity, specific heat, and density of boiling liquid and taking the square root of this product) and square root of bubble emission frequency.

The second factor represents the part of the heat removed by latent heat transport during the formation of the vapor bubbles until their departure.

The quantity $\frac{1}{6} \rho v \; \lambda f Db \frac{1}{\Delta Tw}$ reflects this portion of heat transfer coefficient. The Db is the diameter of the bubble at the time of departure and ΔTw is the degree of wall superheat.

CONCLUSIONS

Following conclusions can be drawn from this investigation:

1. Although, the heat transfer rates in nucleate pool boiling are contributed by both conduction and latent heat transport, the conduction heat transfer plays more significant role.

2. The role of latent heat transport by vapor bubbles increases as heat flux and pressure increases.

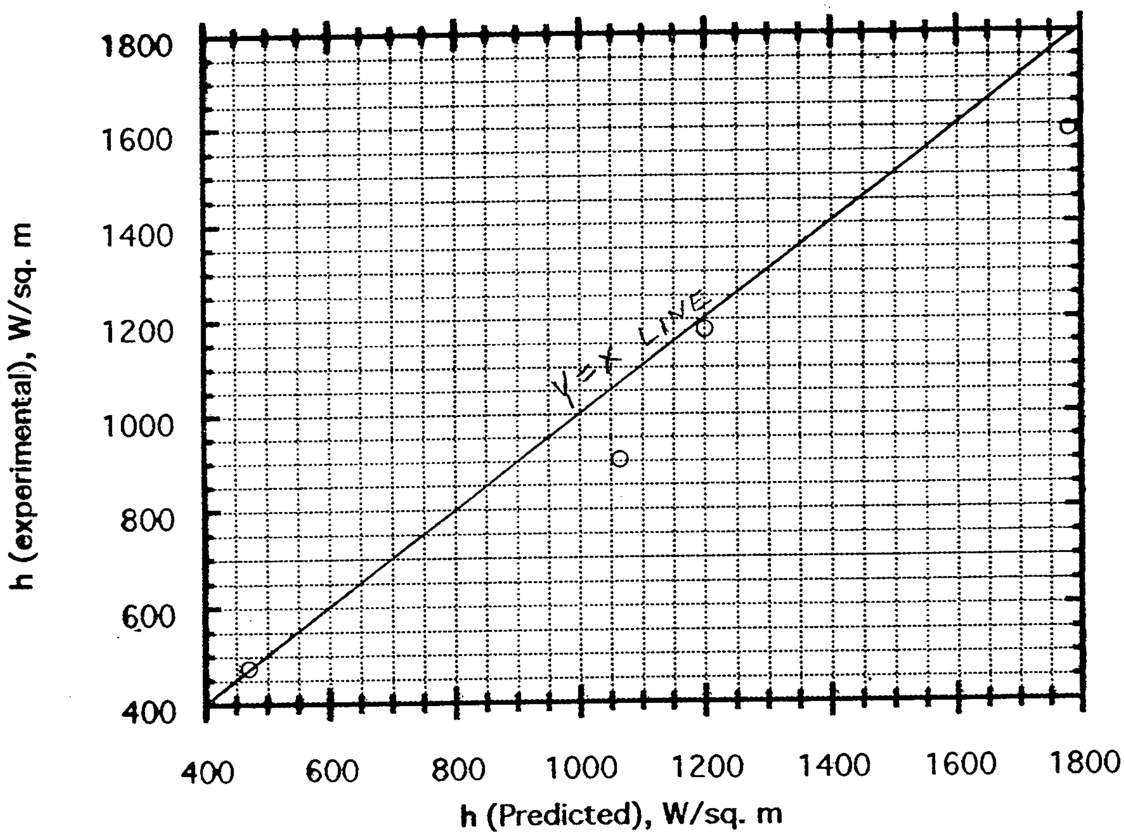
3. The data correlates very well with the experimental data of all the refrigerants investigated at low pressures.

RESULTS

Heat transfer coefficients were calculated using this correlation for the data of Engelhorn as shown in Table-1. As we developed our correlation only for atmospheric and subatmospheric pressures we conducted the calculations mostly for lower pressures. We also did some calculations for higher pressures. The predicted values of heat transfer coefficient were compared with the experimental values reported by Engelhorn. The correlation predicted the data remarkably well.

The calculations for heat transfer coefficients were done by calculating two factors separately as given in the correlation. Following Tables show the values of these factors. An inspection of these Tables reveal that the role of latent heat transport increases as pressure and heat flux increase. At lower values of heat flux and pressure the latent heat factor is almost insignificant in comparison to the heat removed due to conduction.

Experimental Data for R-11 at 0.019 bar vs Present Analysis



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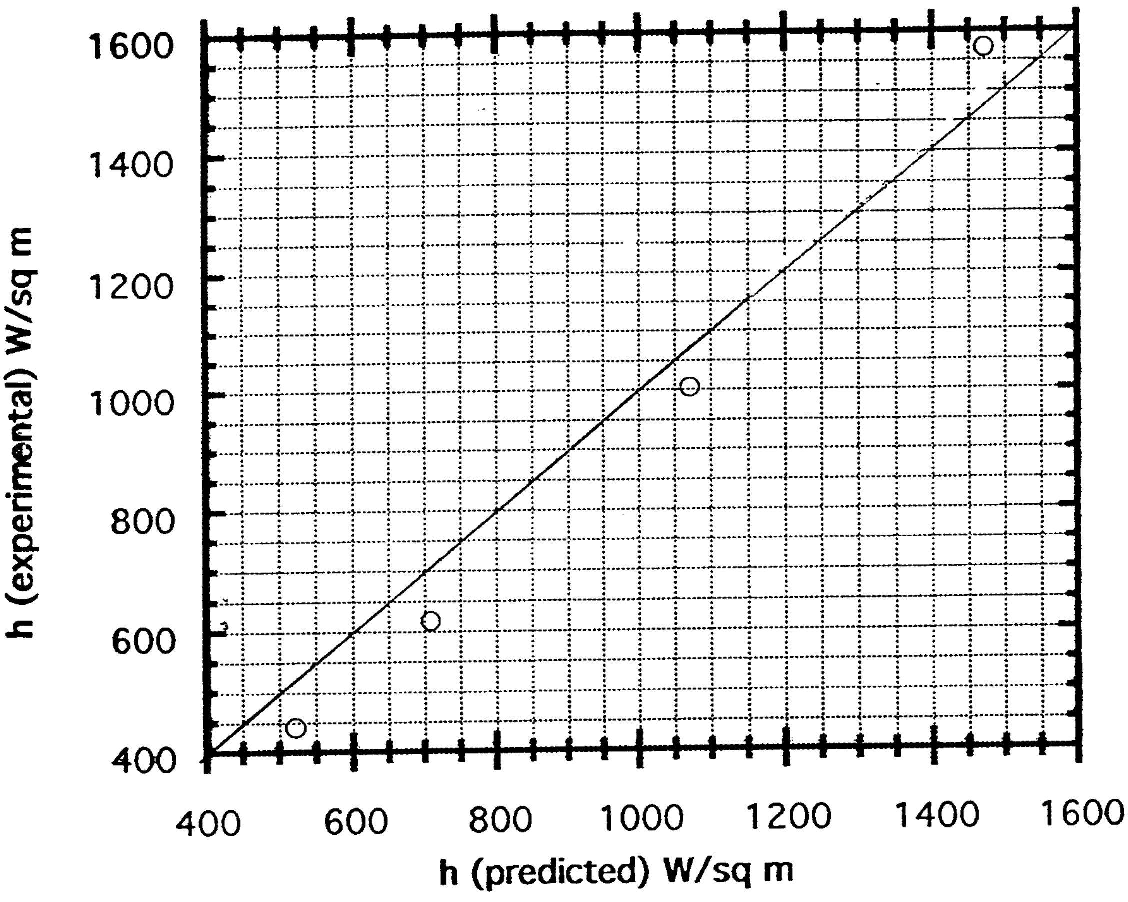
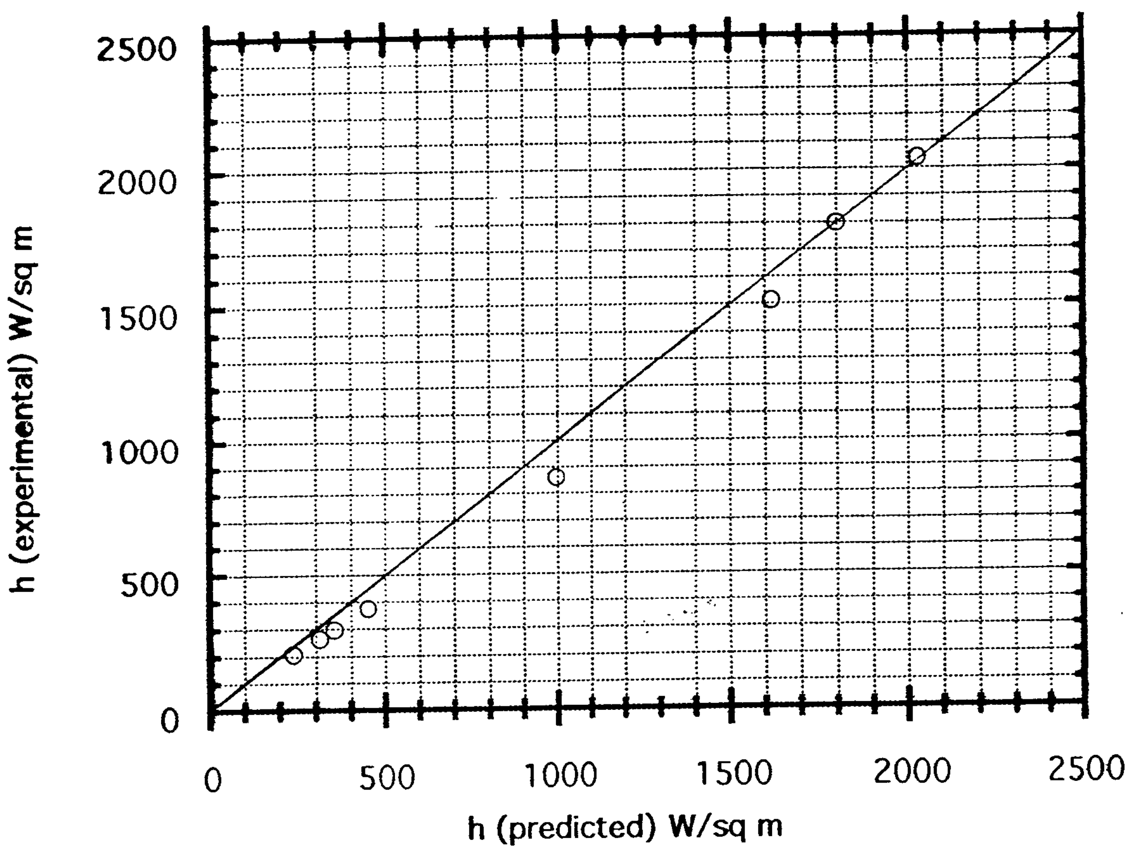
4. Blöchl, R. " Zum Einfluβ der Oberflächenstruktur unterschiedlich bearbeiteter Heizflächen auf die Wärmeübertragung beim Blasensieden", Diss., Universität Karlsruhe (TH), 1986.

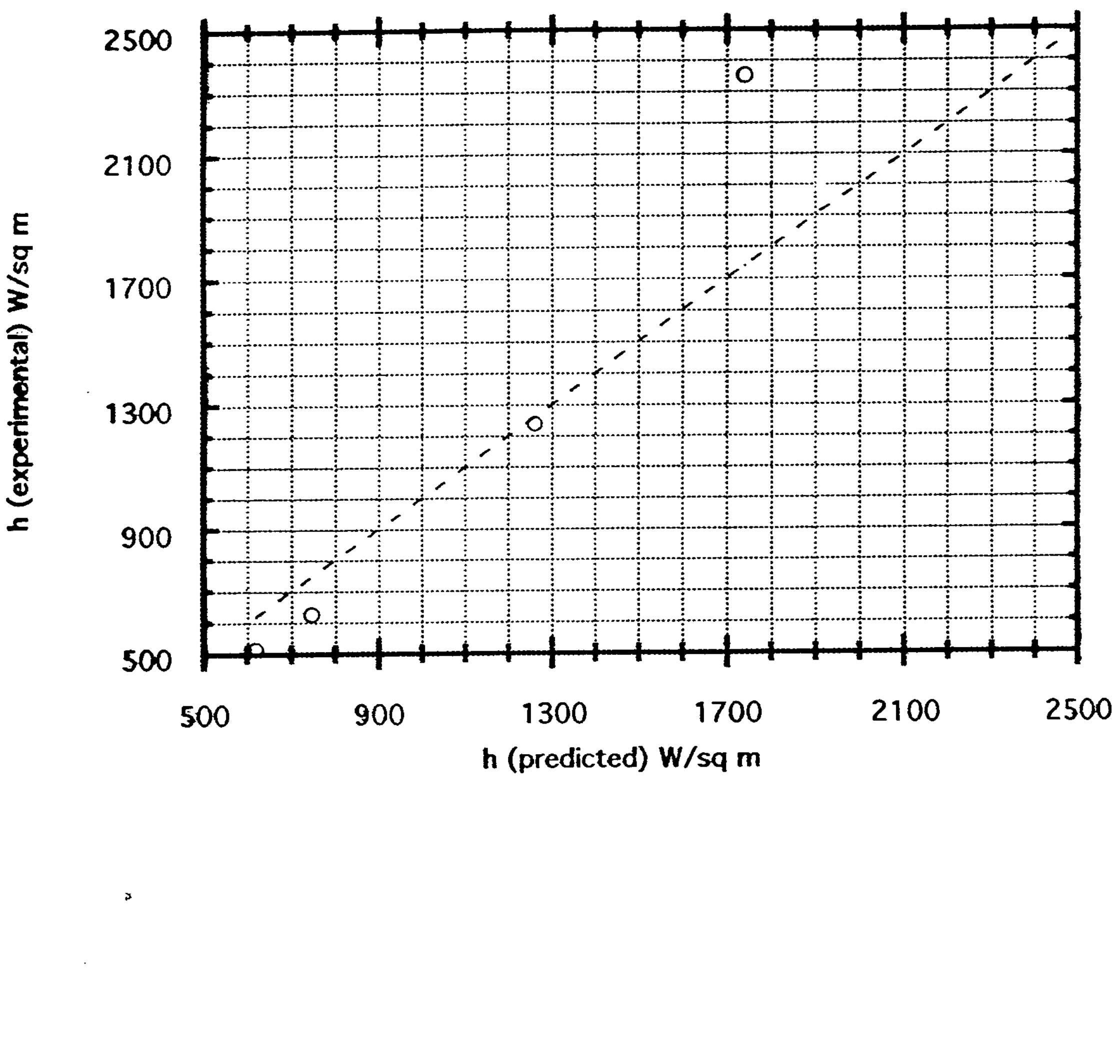
Experimental Data for R-11 at 0.105 bar vs Present Analysis



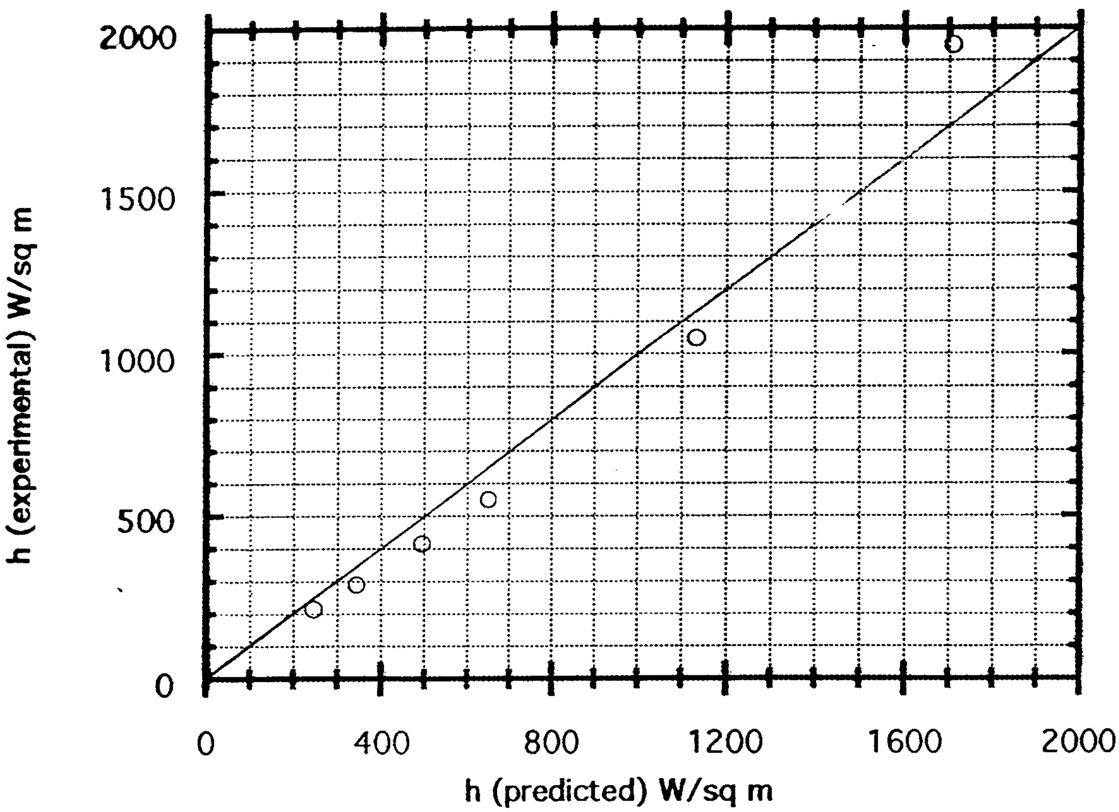
Experimental Data for R-11 at 0.028 bar vs Present Analysis



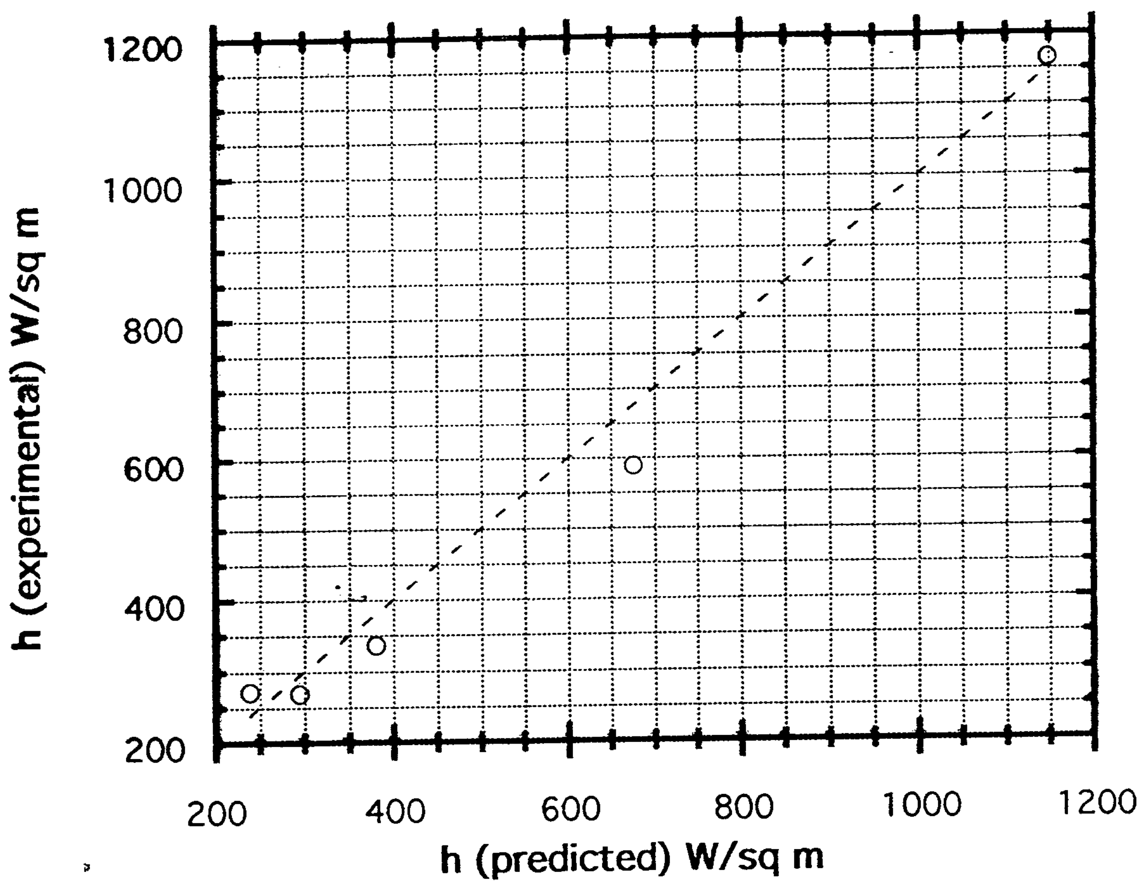
Experimental Data for R-11 at 0.991 bar vs Present Analysis



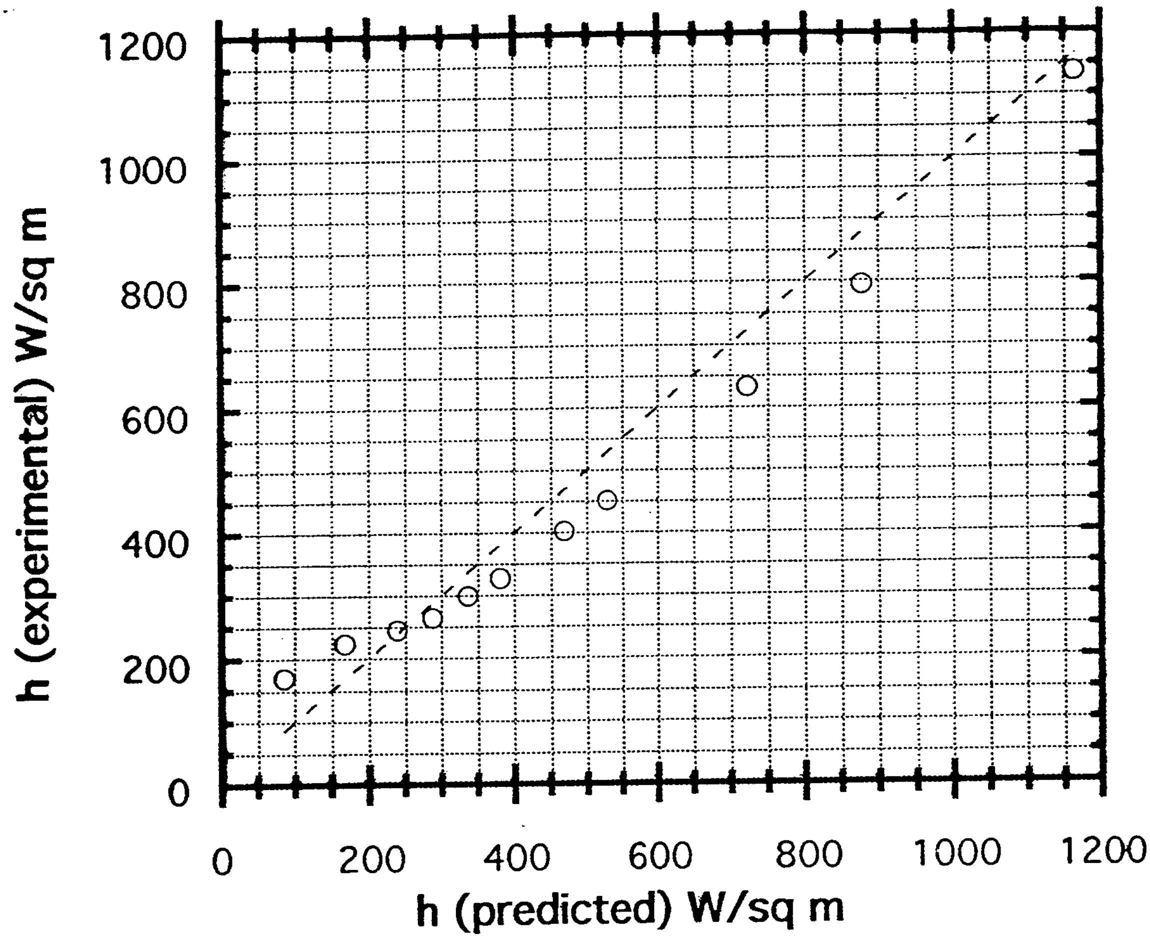
Experimental Data for R-11 at 0.503 bar vs Present Analysis



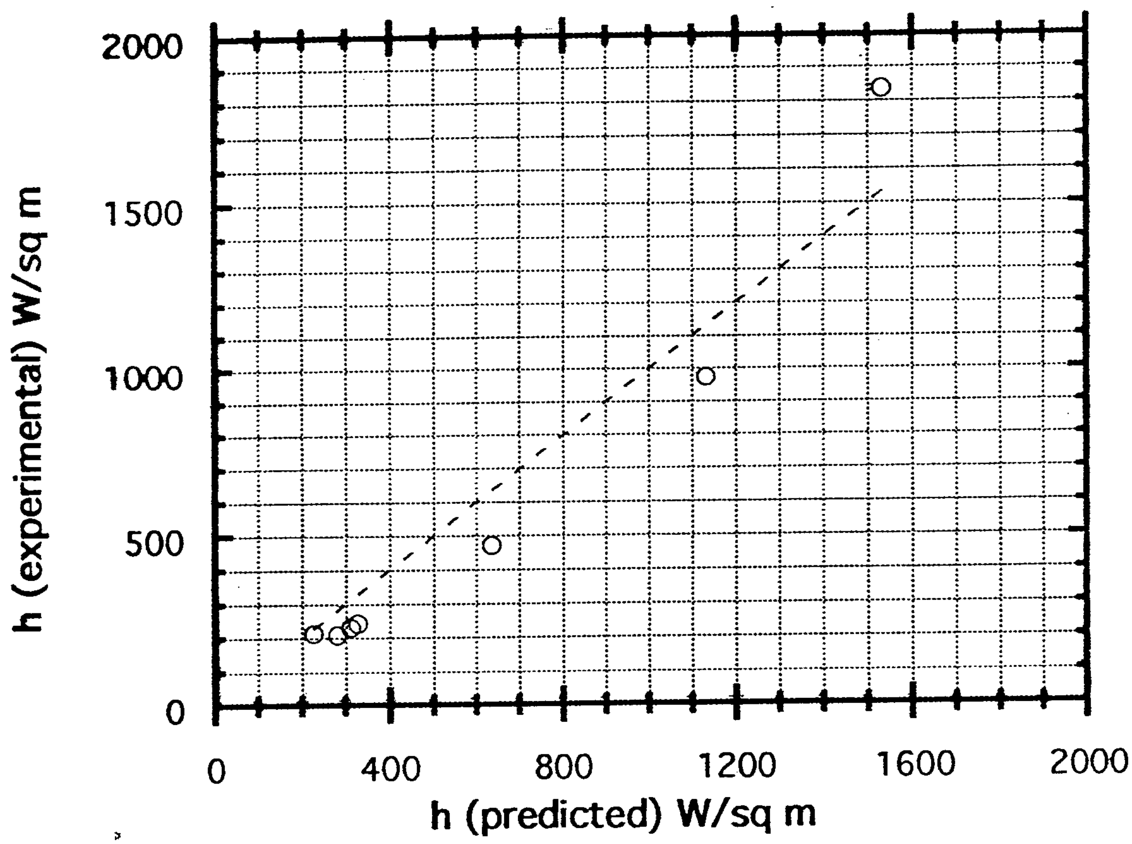
Experimental Data for R-12 at 0.50 bar vs Present Analysis



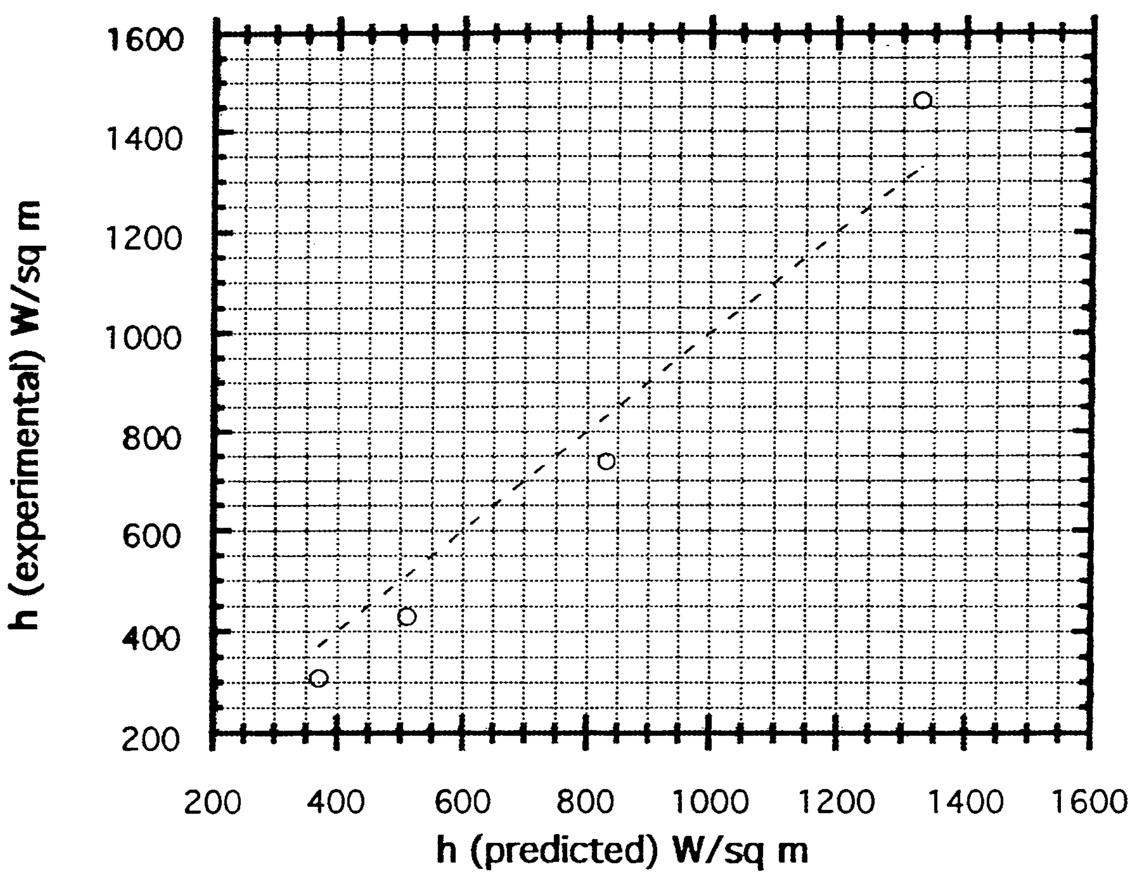
Experimental Data for R-12 at 0.25 bar vs Present Analysis



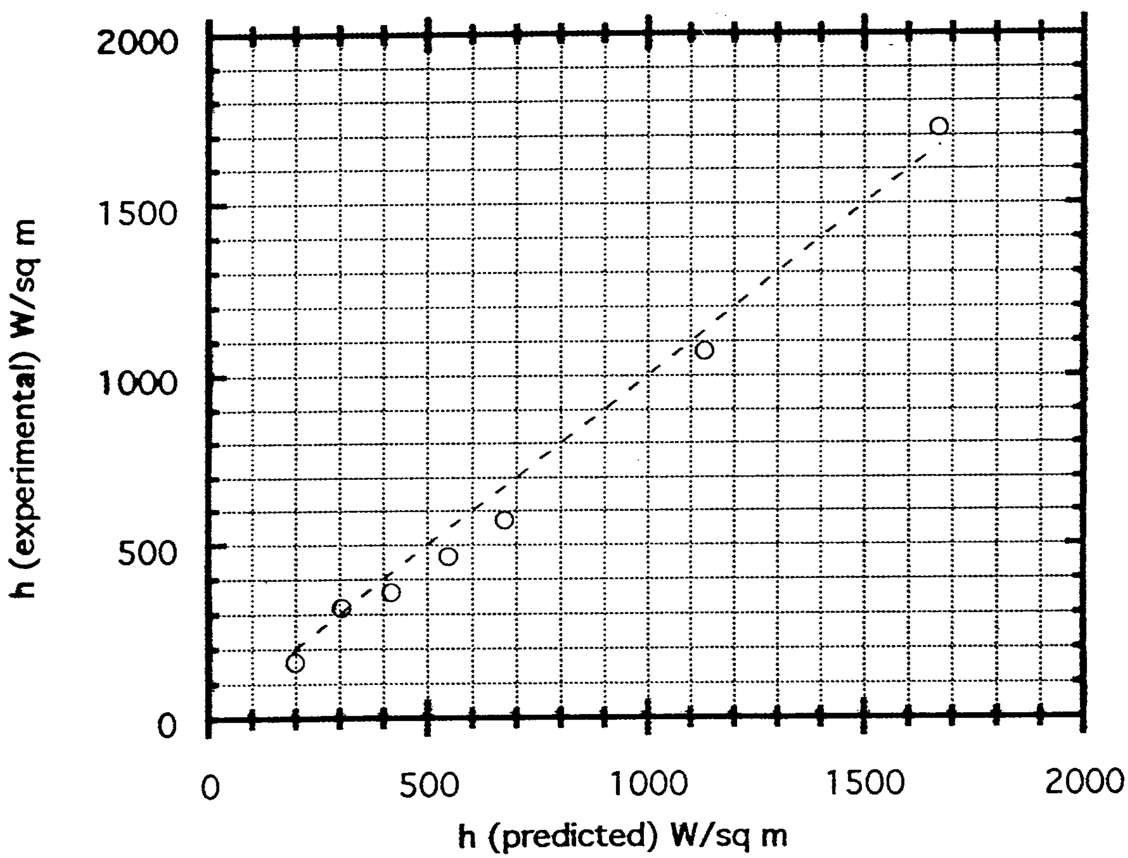
Experimental Data for R-13 at 2.80 bar vs Present Analysis



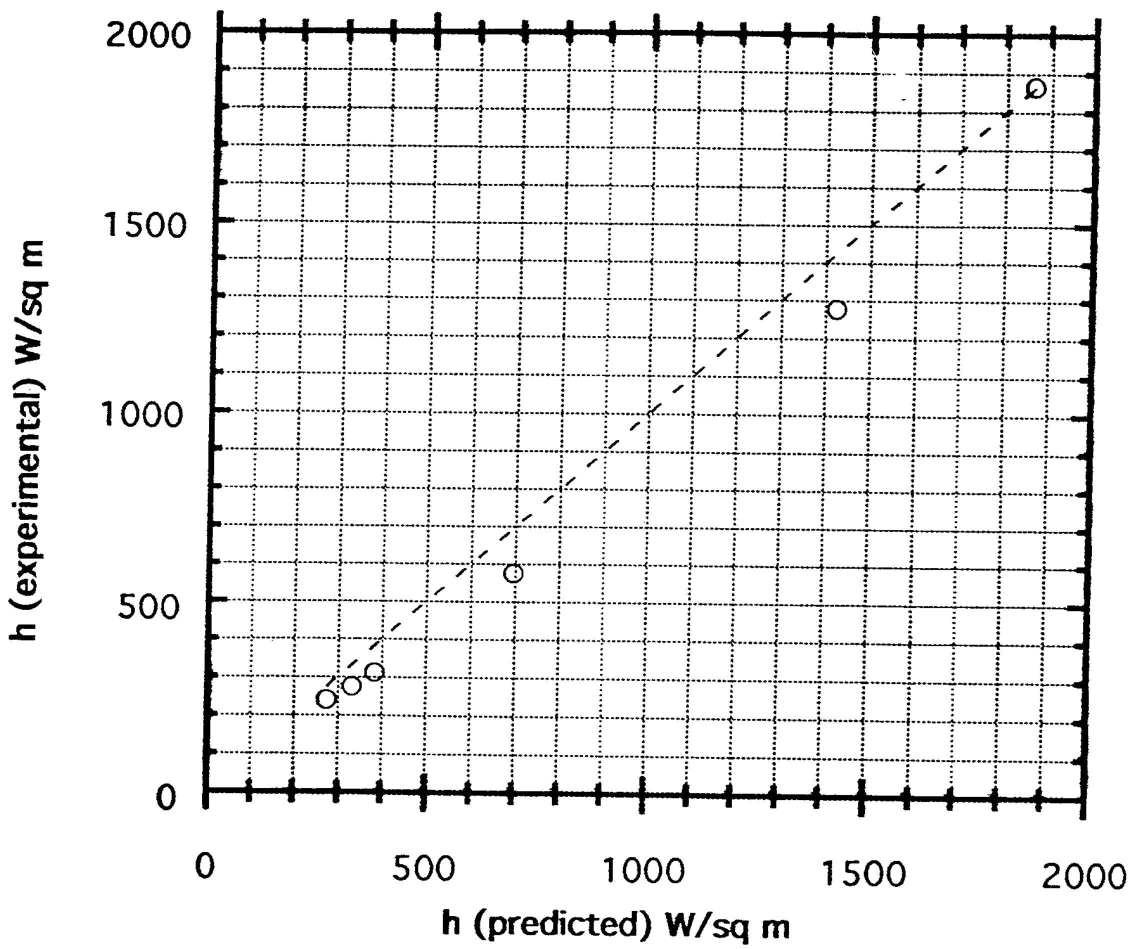
Experimental Data for R-12 at 1.00 bar vs Present Analysis



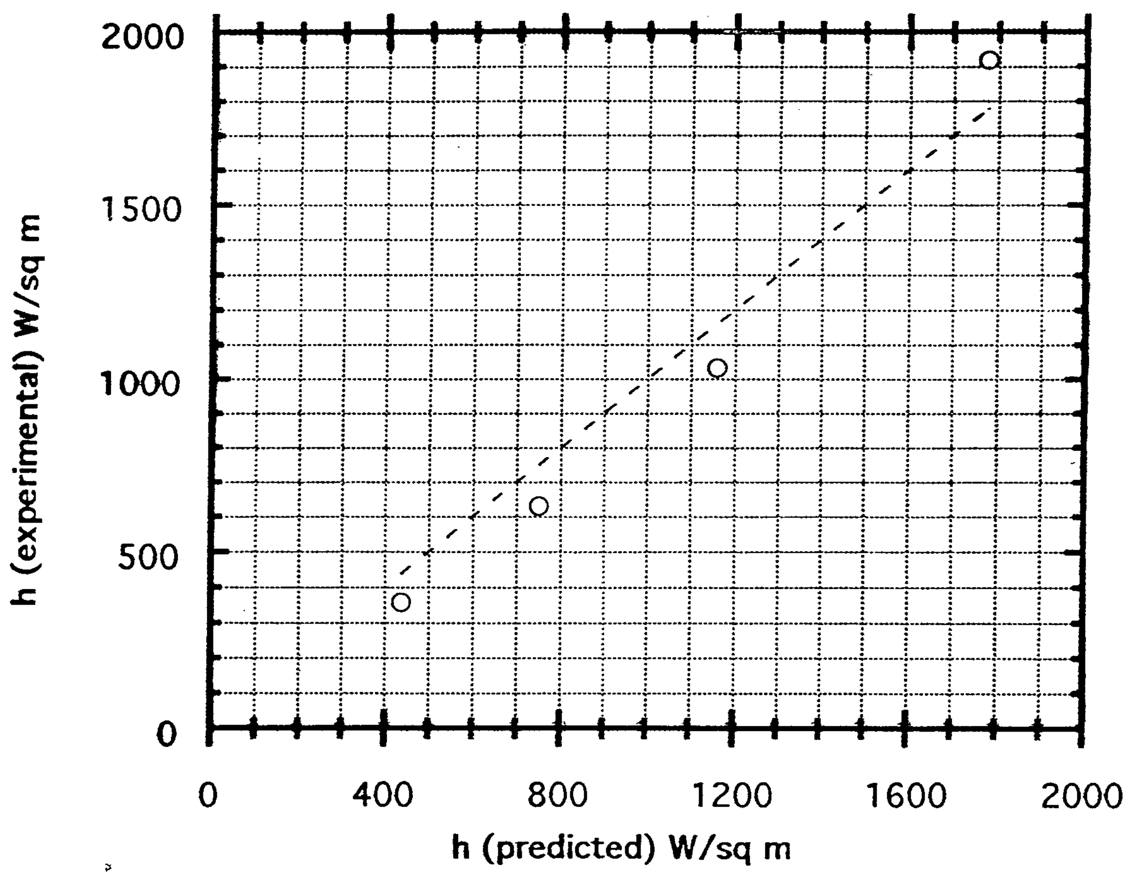
Experimental Data for R-22 at 0.390 bar vs Present Analysis



Experimental Data for R-13B1 at 0.78 bar vs Present Analysis



Experimental Data for R-22 at 0.84 bar vs Present Analysis



Experimental Data for R-22 at 2.15 bar vs Present Analysis